



## NAVY EXPERIMENTAL DIVING UNIT



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MANNED DIVING FOR INTELLIGIBILITY  
ASSESSMENT OF EBS-II COMMUNICATION  
SYSTEM COMPONENTS WITH HELIOX AND  
NITROX BREATHING MEDIUMS

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| <p>In October 1996, manned dives were conducted to evaluate the ability of the MK-24 microphone and AN/PQS headset communications components to produce intelligible speech while diving with the MK-16 MOD 0 Underwater Breathing Apparatus (UBA) in closed and open circuit modes and while breathing HeO<sub>2</sub> and N<sub>2</sub>O<sub>2</sub> at various depths.</p> <p>The objectives were to evaluate the ability of the MK-24 microphone to produce intelligible speech with divers breathing HeO<sub>2</sub> (0.7PPO<sub>2</sub>) to 300 fsw and shallower both with and without a helium speech unscrambler (HSU).</p> <p>To evaluate the ability of the MK-24 microphone to produce intelligible speech with divers breathing N<sub>2</sub>O<sub>2</sub> (0.7PPO<sub>2</sub>) in closed-circuit mode and air in the open-circuit mode to 150 fsw and shallower.</p> <p>To evaluate the ability of the AN/PQS headset to reproduce intelligible speech from topside and between divers breathing HeO<sub>2</sub> (0.7PPO<sub>2</sub>), N<sub>2</sub>O<sub>2</sub> (0.7PPO<sub>2</sub>) and air to 300 fsw and shallower both with and without an HSU.</p> |   |   |                            |
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To evaluate at what depth, to 300 fsw, it becomes necessary to use an HSU to obtain satisfactory speech intelligibility with divers breathing HeO<sub>2</sub> (0.7PPO<sub>2</sub>).

To evaluate the general performance of alternate communications amplifiers that might be available for this test. This was a secondary objective and was not to interfere with achieving the above objectives.

The test was conducted at various depths with the test diver at rest in the wet pot of a pressure vessel assembly (PVA) at the Naval Diving and Salvage Training Center (NDSTC). Each diver wore a MK-16 UBA with a MK-24 FFM and used a microphone and headset connected via the chamber communication penetrator to a topside communication's amplifier (Hydrocom).

For a NITROX breathing medium, the objective and subjective results indicate that the EBS-II communications system components, as tested, can produce acceptable round-robin intelligibility to 150 fsw. For a HELIOX breathing medium, acceptable diver to topside and topside to diver intelligibility was obtained using these same components. Poor diver to diver intelligibility was a result of limited bottom time, inadequate HSU adjustment, and lack of diver experience with unscrambled (HSU on) and scrambled (HSU off) helium speech. Subjective results indicate that scrambled helium speech from divers can be understood by topside personnel down to approximately 100 fsw.

Based on the findings of this report, the communications components of the EBS-II system, as tested, are recommended for use by EOD to support round robin communications for NITROX as well as topside to diver and diver to topside communication for HELIOX diving.

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## **INTRODUCTION**

There is a need to provide intelligible and reliable round-robin diver communication to 300 fsw and shallower using systems currently deployed, and expected to be deployed, to Naval Explosive Ordnance Disposal (EOD) units. There are a number of challenges to be met in satisfying this requirement.

The currently deployed EOD Emergency Breathing System Type II (EBS II) has a communication system that comprises four main components; a surface communications amplifier, diver headset, diver microphone and communication cable. The current, Approved for Navy Use (ANU), HYDROCOM surface communication amplifier is no longer in production and a new amplifier must be identified and tested. The other system components must be verified to work adequately with this new amplifier to depths of up to 300 fsw using both nitrox and heliox breathing mediums. Testing of a new communication amplifier must include system testing using the components that are intended to be fielded. However, prior to this the performance of the individual components must be characterized to 300 fsw and shallower using heliox and nitrox breathing mediums.

The diver microphone, fitted to a MK-24 full face mask (FFM), is a new design that has not been adequately tested in a heliox speech environment. The diver headset, acquired from the AN/PQS2A sonar program, was not originally intended to be used for reproducing human speech and must also be tested.

In the event of poor system performance, not knowing the performance characteristic of the individual components will make it difficult to determine which are performing poorly and will result in inconclusive test results. On the other hand, good system performance implies all components are working acceptably well. Only after it is determined that all system components can perform acceptably will system testing with a new, candidate, communication amplifier be conducted.

## **OBJECTIVES**

This test report documents a manned, in-water, dive series conducted at the Navy Diving and Salvage Training Center (NDSTC). Heliox decompression dives were conducted to 300 fsw and nitrox decompression dives were conducted to 150 fsw.

The general objective was to evaluate the ability of the Type A MK-24 microphone, communication cable, and AN/PQS2A headset communication components to produce intelligible speech while diving with the MK-16 Mod 0 in closed- and open-circuit modes using nitrox and heliox breathing mediums to 300 fsw. This does not specifically include the evaluation of a topside communication amplifier as a primary objective. More extensive testing of communication amplifiers will occur at a future date. For the

majority of these tests, a Hydrocom communications amplifier with a helium speech unscrambler (HSU) was used. This amplifier has known performance characteristics.

## SPECIFIC OBJECTIVES

- a. At depths to 300 fsw, evaluate the intelligibility of speech from a diver breathing heliox (0.75 PPO<sub>2</sub>) while using the MK-24 diver microphone and Hydrocom amplifier with HSU.
- b. At depths to 150 fsw, evaluate the intelligibility of speech from a diver breathing nitrox (0.75 PPO<sub>2</sub>) while using the MK-24 diver microphone in open- and closed-circuit modes.
- c. At depths to 300 fsw, evaluate the ability of the AN/PQS2A headset to reproduce intelligible speech from topside and between divers breathing heliox and nitrox both with and without an HSU.
- d. Evaluate at what depth, to 300 fsw, it becomes necessary to use an HSU to obtain satisfactory speech intelligibility with divers breathing a heliox mix.
- e. Evaluate the general performance of alternate communications amplifiers that might be available for this test. This is a secondary objective and is not to interfere with achieving objectives a. through d. above.

## EVALUATION METHODS

A series of manned dives were conducted under a NEDU test plan<sup>1</sup> in the wet pot of a pressure vessel assembly (PVA) at NDSTC. NDSTC provided personnel to supervise the dive and conduct the operations of the PVA. NEDU provided the test plan and divers.

Each diver used a MK-16 Mod 0 underwater breathing apparatus (UBA) with a MK-24 full face mask (FFM). In this configuration the MK-24 microphone is screwed into the switchover block of the FFM and each speaker element of an AN/PQS-2A sonar headset is secured over the diver's ears using a skull cap. The sonar headset is used for voice communications in order to meet the EOD low magnetic signature requirements. Detailed descriptions of the diver headset and microphone are found in Appendix D.

All divers were young adult male divers with current audiograms and normal hearing. All were qualified Navy divers experienced in the use of diving equipment. Divers wore wetsuits for both dive series and the water was no less than 70 degrees Fahrenheit. Wetsuit hoods were not worn so that the headset speaker elements could be placed over the divers ears with only the skull cap material in between. Divers

remained submerged throughout the tests and sat or stood in a comfortable position with the best possible lighting while performing the test procedures. Prior to testing each diver was instructed to ensure they had adequate visibility through the FFM.

For these tests each diver had a separate 4-wire communication cable connecting their microphone and headset to an individual channel on the communication amplifier. This is consistent with EOD's plan to allow only single diver communication on the cable assembly currently deployed with the EBS-II. A full length EBS-II umbilical comprising a 4-wire communication cable, an air hose and a strength member was used between each diver and the PVA wet pot electrical penetrator. Additional cabling was used to connect each of the diver communication channels from the PVA penetrator to the HYDROCOM communication amplifier which was setup outside the PVA. For open-circuit tests, the gas hose in the EBS-II umbilical was used to provide a nitrox breathing mix. There were no observed problems during the testing, however, no attempt was made to measure or determine the effects of externally generated EMI on this communication system.

Because each EBS-II cable assembly was originally designed to support communications for two divers it has two sets of microphone and headset connectors at the diver end. For these dives only one set of connectors was used and the other set was waterblocked using dummy mating connectors.

A digital audio tape (DAT) recorder was connected to the tape output jack of the amplifier and was used to record all diver conversation throughout the dive series.

Speech intelligibility was evaluated using both objective and subjective methods. Objective evaluation methods included use of the Modified Rhyme Test (MRT). Subjective evaluation methods included use of questionnaires, real-time and post-dive verbal feedback from the divers and topside listeners, and post-dive evaluation of the DAT recordings that were made throughout the dives. A description of these methods follows:

### **Modified Rhyme Test**

The Griffith (1967) version of the MRT was used as an objective method for evaluating round-robin communication intelligibility between divers and topside for both dive series. It was chosen for its ease of administration and scoring, its stability with respect to learning effects, and because it requires minimal listener training. Although the MRT is not phonetically balanced and does not present words in a contextual format to represent everyday speech, it is efficient and useful because it requires perception of consonantal sounds (sounds that are difficult to transmit successfully) and are thus more important than vowels to intelligibility.

For diver-to-diver testing, each diver read a different word list to his partner who responded on the appropriate response sheet. To increase the number of MRT words that could be tested in a short bounce dive, the rate of reading was primarily controlled by the responding diver who indicated his readiness to go on to the next word with a verbal queue (i.e. "go") or silence which was implied to mean he was ready to proceed. If topside or the responding diver thought that the reading rate was too high the reading diver was told to slow down. Usually, after a few words were read, an acceptable reading rate was established.

For topside-to-diver testing, topside reads a word list to both divers simultaneously who respond on the appropriate response sheet. The rate of reading was controlled using the same method as used for diver-to-diver MRTs. Diver-to-topside testing was not conducted during the dive series. Evaluation of diver-to-topside intelligibility could be conducted post-dive using DAT recordings of the diver-to-diver MRTs.

A number of different word lists and response lists were used during the testing. These lists were distributed among the tests so that no dive pair ever repeated a test using the same word list, response sheet combination. All test divers were given practice MRT sheets to familiarize themselves with the MRT procedures prior to the dives.

An MRT reading list (Appendix A) contains 50 monosyllabic words each. Talkers preface each test word on a reading list with the phrase "The word is \_\_\_\_." This procedure serves to alert the listener and allows the talker to adjust his voice level. Each listener responds on a response sheet (Appendix A) matched to the word list. For each word on a word list, the listener has five possible words on the response sheet to select from. The listener then circles the word he hears from the five and goes to the next line. For each word list there are six different response sheets that each change the order of words within the set of possible responses to the corresponding word on the word list.

To determine the percent correct for the MRTs, the following formula, which takes into account the 20% guessing factor, is used (Van Cott and Kinkade, 1972):

$$\% \text{ correct} = 2 \times (\text{number right} - \text{number wrong}/4)$$

If a full reading list is not completed a correction factor is applied to the above formula so that:

$$\begin{aligned}\% \text{ correct} &= (100/\text{total number of words completed}) \times (\text{number right} \\ &\quad - \text{number wrong}/4)\end{aligned}$$

The intelligibility criteria for military voice communications systems is set forth in MIL-STD-1472D<sup>2</sup>. This standard sets 75% as the minimum acceptable intelligibility

score when using the MRT as the evaluation criteria. This standard also indicates that a 75% score is not acceptable (too low) for operational equipment, however, the discontinued HYDROCOM Model UDC-225 communication amplifier was recommended for approval by NEDU<sup>3,4</sup> using this minimum scoring criteria and subsequently approved for Navy use by NAVSEA. For heliox diving, NEDU technical memorandum<sup>5</sup> indicates that NAVSEA has approved an MRT score of 60% as a passing criteria for diver operational equipment. Therefore, the minimum acceptable MRT intelligibility criteria used for this testing was 75% for nitrox speech and 60% for helium speech.

## QUESTIONNAIRES

Subjective evaluation of topside-to-diver, diver-to-topside and diver-to-diver intelligibility was done using responses from questionnaires that were filled out by the divers and topside after each dive. Many of the questions came from a study on helium speech intelligibility<sup>6</sup> and were tailored to suit these tests. The questions probed perceptions of the communication system. The responses served to supplement the objective data from the MRTs, however, by themselves they can provide a very good subjective indicator of intelligibility.

A six point scale (6 being best, 1 being worst) was used to rate different perceptual aspects of the system, such as background noise, level of speech distortion, clarity, and ability to understand individual words and conversation. Refer to the questionnaire average response figures for lists of the rated questions. Responses from questions 2, 3 and 4 provide the most direct subjective rating of speech intelligibility and a score of 4 or higher could be considered acceptable. The other rated questions, 1, 5, and 6 addressed background noise and comparative speech distortion which are symptoms effecting speech intelligibility. Because of the nature of these questions and the rating scale it is more problematic to assign an acceptable rating level. For example, background noise could be obviously disruptive (i.e. inhalation noise in open-circuit mode) yet word and speech intelligibility could be acceptable. Generally speaking, a rating of 4 or higher would indicate that there is a high probability of acceptable speech intelligibility but it is not necessarily a prerequisite.

There were also questions that invited comments about which speech sounds came through best and worst, how the communication system effected the speech, and what discomfort might have been experienced. For a list of these questions refer to Appendices B and C.

## DIGITAL AUDIO TAPE RECORDINGS

DAT recordings were made of all communications throughout the dives. These tapes allowed post-dive subjective evaluation of round-robin intelligibility. For the heliox dives, recordings were made of the divers reading supplied material during ascent and

descent without an HSU in order to determine the effects of depth on scrambled helium speech intelligibility. Other recordings of diving related procedural conversation and casual social conversation make it easy to get an idea of the level of intelligibility by listening to the response of the listener after being spoken to. If the listeners respond in a logical fashion and the talker is not asked to repeat himself then intelligibility could be considered adequate. If the talker is often asked to repeat himself then the intelligibility could be considered poor. Post-dive test subjects who listen to these tapes would be qualified to fill out diver-to-topside questionnaires thus adding to the evaluation data base. As with the questionnaires, these tapes supplement the objective data from the MRTs, however, by themselves they can be a very good subjective indicator of intelligibility.

## VERBAL FEEDBACK

During and after the dives, conversations with the divers and topside listeners provided valuable information on the performance of the communication system. Real-time verbal feedback was used to help evaluate the depth limits for scrambled helium speech intelligibility. This was tested by having divers on a heliox breathing mixture read paragraphs during descent and ascent. While changing depth, topside listeners provided verbal feedback as to when they could no longer understand (descent) or begin to understand (ascent) the material being read. The depth at this point was noted.

## PROCEDURES

The manned dive series was conducted from 2 through 4 October 1996. This series used 4 divers and comprised 6 decompression dives; 2 using a nitrox breathing medium and 4 using heliox. For all dives, the inhalation noise attenuation circuitry (INAC) on the HYDROCOM communication amplifier was turned off. The dives, dive team assignments, depth and bottom times were scheduled as follows:

- Day 1:      Dive team #1, 100 fsw heliox, 40 minute bottom time  
                Dive team #2, 100 fsw nitrox, 40 minute bottom time
- Day 2:      Dive team #1, 200 fsw heliox, 20 minute bottom time  
                Dive team #2, 150 fsw nitrox, 20 minute bottom time
- Day 3:      Dive team #1, 300 fsw heliox, 15 minute bottom time  
                Dive team #2, 300 fsw heliox, 15 minute bottom time

## NITROX DIVES

These tests were conducted in both open- and closed-circuit breathing modes at two depths; 1) 150 fsw, the maximum certified depth for the MK-24 FFM open circuit regulator, and 2) 100 fsw, the maximum decompression stop depth for the current MK-16 MOD 0 with the EBS II. Testing was conducted as follows:

**150 fsw:**

At test depth diver-to-diver MRTs are conducted first in closed-circuit mode and then repeated in open-circuit mode. While in open-circuit mode a topside-to-diver MRT is conducted.

- (1) With divers in the water in closed-circuit mode and the wet pot on the surface perform a communication check and adjust diver and topside volumes on the Hydrocom communication amplifier as required. The Hydrocom INAC and HSU shall both be turned off.
- (2) Provide divers with necessary printed material and equipment.
- (3) Close wet pot, submerge divers in closed circuit mode and record ambient background noise for approximately 10 seconds with both diver microphones open, divers still and tender microphone off. Audio recording will continue from this point throughout the dive.
- (4) Press divers to depth. During descent Red diver will read supplied material at a comfortable rate all the way to the bottom.
- (5) After reaching bottom, test round-robin communications again and adjust volumes to each diver-subject's preferred level as required.
- (6) Record ambient background noise for approximately 10 seconds with both diver microphones open, divers still and tender microphone off.
- (7) Green and Red diver are notified by topside to get ready to begin. Wait for both divers to indicate they are ready to begin.
- (8) Green diver reads first word list to Red diver and Red diver records on respective response sheet. Green diver stops reading only after being notified by topside.
- (9) Red diver reads first word list to Green diver and Red diver records on respective response sheet. Red diver stops reading only after being notified by topside.
- (10) Green and Red diver switch to open-circuit mode.
- (11) Test round-robin communications again and adjust volumes to each diver-subject's preferred level as required.

- (12) Record ambient background noise for approximately 10 seconds with both diver microphones open, divers still and tender microphone off.
- (13) Green diver reads second word list to Red diver and Red diver records on respective response sheet. Green diver stops reading only after being notified by topside.
- (14) Red diver reads second word list to Green diver and Green diver records on respective response sheet. Red diver stops reading only after being notified by topside.
- (15) Divers are notified to prepare to respond to word list read by topside.
- (16) When both divers signal ready, divers respond to word list read by topside.
- (17) Divers are notified to prepare to ascend to first decompression stop.
- (18) Divers ascend to first decompression stop.
- (19) During the decompression stops, as conditions and equipment permit, connect alternate communication amplifiers to divers and perform intelligibility tests using word lists or other material.
- (20) Divers surface
- (21) Divers fill out questionnaire.

**100 fsw:**

In closed-circuit mode, one diver reads paragraphs while descending to test depth. At test depth, diver-to-diver and topside-to-diver MRTs are conducted first in closed-circuit mode and then repeated in open-circuit mode.

- (1) Repeat sequence 1-9 from the 150 fsw N<sub>2</sub>O<sub>2</sub>/AIR dive.
- (2) Closed circuit mode. Divers are notified to prepare to respond to word list read by topside.
- (3) When both divers signal ready, divers respond to word list read by topside.
- (4) Repeat sequence 10-21 from the 150 fsw N<sub>2</sub>O<sub>2</sub>/air dive.

## **HELIOX DIVES**

These tests were conducted both with and without a helium speech unscrambler at three depths and during ascent/descent. The test depths were; 1) 300 fsw, the maximum depth expected to be supported by the MK-16 Product Improvement Program (PIP), 2) 200 fsw, the approximate maximum depth (actual is 190 fsw) supported by the current MK-16 MOD 0 and, 3) 100 fsw the maximum decompression stop depth for the current MK-16 MOD 0 with the EBS II. Testing was also done during ascent/descent to subjectively determine the depth above which an HSU is not required to understand speech in helium using the equipment under test.

The first heliox dive to 100 fsw was terminated early with no decompression stops required. Initially, after reaching 100 fsw, it was discovered that no grease pencils were available to do the tests. One of the divers was unable to clear to test depth again after the wet pot was brought to the surface to retrieve grease pencils. No MRTs were completed. The only data that was acquired was a DAT recording of paragraphs that were read by the divers during ascent and descent and general diver-to-diver and diver-to-topside conversation. The MRT test procedure for this dive was later conducted at the 120 fsw through 90 fsw decompression stops of the first 300 fsw heliox dive.

### **300 fsw, Dive #1:**

With the HSU off, one diver reads paragraphs while descending to test depth. A topside-to-diver MRT is conducted followed by diver-to-diver MRTs with the HSU off. Then a single diver-to-diver (green-to-red) MRT is conducted with the HSU on. The other diver reads paragraphs while ascending to the first stop with the HSU off.

- (1) With divers in the water in closed-circuit mode and the wet pot on the surface perform a communication check and adjust diver and topside volumes on the Hydrocom communication amplifier as required. The Hydrocom INAC and HSU shall both be turned off.
- (2) Provide divers with necessary printed material and equipment.
- (3) Close wet pot, submerge divers and record ambient background noise for approximately 10 seconds with both diver microphones open, divers still and tender microphone off. Audio recording will continue from this point throughout the dive.
- (4) Press divers to depth. During descent Red diver will read supplied material at a comfortable rate all the way to the bottom.

- (5) After reaching bottom, test round-robin communications again and adjust volumes to each diver-subject's preferred level as required. Note settings on communications amplifier.
- (6) Record ambient background noise for approximately 10 seconds with both diver microphones open, divers still and tender microphone off.
- (7) Divers are notified to prepare to respond to word list read by topside.
- (8) When both divers signal ready, divers respond to word list read by topside.
- (9) Green and Red diver are notified by topside to get ready to begin reading word lists to each other. Wait for both divers to indicate they are ready to begin.
- (10) Green diver reads first word list to Red diver and Red diver records on respective response sheet. Green diver stops reading only after being notified by topside.
- (11) Red diver reads first word list to Green diver and Green diver records on respective response sheet. Red diver stops reading only after being notified by topside.
- (12) Change HSU control on Hydrocom box to "in" (HSU on).
- (13) While Green diver reads printed material, adjust HSU controls to produce the most intelligible speech for Green diver as determined by a consensus of topside personnel and Red diver. Note position of controls.
- (14) Record ambient background noise for approximately 10 seconds with both diver microphones open, divers still and tender microphone off.
- (15) Green and Red diver are notified by topside to get ready to begin. Wait for both divers to indicate they are ready to begin.
- (16) Green diver reads second word list to Red diver and Red diver records on respective response sheet. Green diver stops reading only after being notified by topside.
- (17) Change HSU control on Hydrocom box to "bypass" (HSU off).
- (18) Divers are notified to prepare to ascend to first decompression stop.
- (19) Divers ascend to first decompression stop. During ascent Green diver will read supplied material at a comfortable rate until divers reach the stop.

(20) Starting at the 120 fsw decompression stop conduct the MRT sequences from the previously aborted 100 fsw heliox dive; Conduct diver-to-diver MRTs by repeating steps (9) through (16) using the appropriate reading lists and response sheets. Then conduct the topside-to-diver MRT by repeating steps (7) and (8). During this sequence, testing is stopped during excursions to shallower stops.

(21) Divers surface

(22) Divers fill out questionnaire.

**300 fsw, Dive #2:**

With the HSU off, one diver reads paragraphs while descending to test depth. Diver-to-diver MRTs are conducted, first with the HSU off and then with the HSU on. The other diver reads paragraphs while ascending to first stop with the HSU off.

- (1) Repeat sequence 1-6 from the first 300 fsw heliox dive
- (2) Repeat sequence 9-16 from the first 300 fsw heliox dive
- (3) Red diver reads second word list to Green diver and Green diver records on respective response sheet. Red diver stops reading when notified by topside.
- (4) Repeat sequence 17-22 from the first 300 fsw heliox dive.

**200 fsw:**

With the HSU off, one diver reads paragraphs while descending to test depth. Diver-to-diver MRTs are conducted, first with the HSU off and then with the HSU on. This is followed by a topside-to-diver MRT. The other diver reads paragraphs while ascending to first stop with the HSU off.

- (1) Repeat sequence 1-6 from the first 300 fsw heliox dive.
- (2) Repeat sequence 9-16 from the first 300 fsw heliox dive.
- (3) Red diver reads second word list to Green diver and Green diver records on respective response sheet. Red diver stops reading only after being notified by topside.
- (4) Divers are notified to prepare to respond to word list read by topside.
- (5) When both divers signal ready, divers respond to word list read by topside.

- (6) Repeat sequence 17-22 from the first 300 fsw heliox dive.

## RESULTS AND ANALYSIS

### NITROX DIVES

Speech intelligibility results and analysis is divided into three sections; topside-to-diver, diver-to-diver, and diver-to-topside. Open- and closed-circuit modes are addressed in each section.

#### Topside-to-diver

##### Modified Rhyme Test Scores

Topside-to-diver speech intelligibility was objectively measured using the average of MRT scores for the open- and closed-circuit nitrox dives (Figure 1).

A high degree of intelligibility was indicated with averages at 100 and 150 fsw ranging from 97.5% to 98.1% in open-circuit mode and an average of 97.5 in closed-circuit mode at 100 fsw. No scores were lower than 95%.

##### Questionnaire Ratings

Topside-to-diver speech intelligibility was subjectively measured using diver responses to five questions that required a numeric rating from a six-point scale. No distinction was made in the questionnaire between open- and closed-circuit modes. An average of these ratings was calculated (Figure 2) for each question.

An acceptable degree of intelligibility was indicated at both depths with all of the average scores 4.5 or higher.

##### Questionnaire Comments

Diver's written responses to questions are found in Appendix A. In general, the responses were favorable and support the assessment of acceptable topside-to-diver intelligibility as indicated by the other evaluation methods.

For the 150 fsw dive, one diver indicated that he had low headset volume and had to concentrate very hard to understand topside. Despite this comment, this diver was able to score 97.5% on the topside-to-diver MRT test. It was discovered afterwards that the umbilicals for red and green diver were switched without notification for this and the first 300 fsw heliox dive (during which one diver also commented on low headset volume). Because of this the volume controls for each diver were swapped on the communication amplifiers. When a diver asked to have his headset volume increased

| Diver    | 100 fsw | 100 fsw | 150 fsw | 150 fsw |
|----------|---------|---------|---------|---------|
|          | O - C   | C - C   | O - C   | C - C   |
| 3        | 100.0   | 95.0    | 100.0   | n/a     |
| 4        | 95.0    | 100.0   | 97.5    | n/a     |
| Average: | 97.5    | 97.5    | 98.8    | n/a     |

**FIGURE 1. TOPSIDE-TO-DIVER; NITROX MRT TEST RESULTS (%)**

| Question | 100 fsw | 150 fsw |
|----------|---------|---------|
| 1        | 4.5     | 4.5     |
| 2        | 5.0     | 4.5     |
| 3        | 5.0     | 4.5     |
| 4        | 5.0     | 4.5     |
| 5        | 5.0     | 4.5     |

(Sample size = 2)

**Key to rated questions; 1 - 5:**

Question #1: How would you rate the background noise from topside?

Question #2: How would you rate the overall clarity of speech from topside?

Question #3: How would you rate your ability to understand single words from topside?

Question #4: How would you rate your ability to understand conversation from topside?

Question #5 How would you rate the level of speech distortion from topside compared to speech you hear on the surface in a normal conversation?

**Key to answers: 1 is worst, 6 is best**

1= extremely disruptive

1= extremely poor

2= obviously disruptive

2= poor

3= slightly disruptive      OR

3= not quite adequate

4= present but not disruptive

4= adequate

5= barely present

5= good

6= not present

6= excellent

**FIGURE 2. TOPSIDE-TO-DIVER; NITROX, AVERAGE OF RESPONSES TO QUESTIONNAIRE**

the wrong volume control was adjusted and there was no increase in volume to this diver but instead to the other diver. This situation was discovered prior to 300' HeO<sub>2</sub> dive #2 and the correct volume controls for each diver were identified. There were no problems with headset volumes during this dive.

#### Digital Audio Tape Recordings

It is apparent when listening to topside-to-diver conversations recorded during the dive that divers were able to understand topside information the first time it was presented in nearly all cases regardless of depth in closed-circuit mode. In open-circuit mode, if topside was talking when the divers were inhaling the information from topside sometimes needed to be repeated. Topside and divers quickly learned to synchronize speaking and breathing to maximize intelligibility in open-circuit mode.

#### Verbal Feedback

Comments from every diver indicated that topside-to-diver intelligibility was better than just acceptable. In the cases where there was low headset volume the divers indicated that they had to concentrate very hard to hear topside but what they did hear was intelligible. This along with the test results justifies retaining the topside-to-diver intelligibility data despite the low handset volume.

#### **Diver-to-diver**

##### Modified Rhyme Test Scores

Diver-to-diver speech intelligibility was objectively measured using the average of MRT scores for the open- and closed-circuit nitrox dives (Figure 3).

A good degree of intelligibility was indicated with averages at 100 fsw and 150 fsw ranging from 86.3% to 92.5% in open-circuit mode and 88.8% to 95% in closed-circuit mode. No scores were lower than 82.5% in either mode. Typically one would expect the open-circuit scores to be reliably lower than closed-circuit because of breathing inhalation noise that occurs in open-circuit mode. However the divers were able to effectively synchronize their breathing to maximize intelligibility. There was a negligible difference between the combined averages (open and closed-circuit) at 100 fsw and 150 fsw.

##### Questionnaire Ratings

Diver-to-diver speech intelligibility was subjectively measured using diver responses to five questions that required a numeric rating from a six-point scale. There was a distinction made between open- and closed-circuit modes in the questionnaire. An average of these ratings was calculated (Figure 4) for each question.

| Diver    | 100 fsw | 100 fsw | 150 fsw | 150 fsw |
|----------|---------|---------|---------|---------|
|          | O - C   | C - C   | O - C   | C - C   |
| 3        | 90.0    | 85.0    | 82.5    | 95.0    |
| 4        | 95.0    | 92.5    | 90.0    | 95.0    |
| Average: | 92.5    | 88.8    | 86.3    | 95.0    |

FIGURE 3. DIVER-TO-DIVER; NITROX MRT TEST RESULTS (%)

| Question | 100 fsw | 100 fsw | 150 fsw | 150 fsw |
|----------|---------|---------|---------|---------|
|          | O - C   | C - C   | O - C   | C - C   |
| 1        | 3.0     | 5.5     | 2.0     | 5.5     |
| 2        | 4.5     | 5.5     | 5.0     | 5.5     |
| 3        | 4.5     | 5.0     | 5.0     | 5.0     |
| 4        | 4.5     | 5.0     | 5.0     | 5.5     |
| 5        | 4.5     | 5.0     | 3.0     | 5.0     |

(Sample size = 2)

Question #1: How would you rate the background noise from the other diver?

Question #2: How would you rate the overall clarity of speech from the other diver?

Question #3: How would you rate your ability to understand single words from the other diver?

Question #4: How would you rate your ability to understand conversation from the other diver?

Question #5: How would you rate the level of speech distortion from the other diver compared to speech you hear on the surface in a normal conversation?

**Key to answers: 1 is worst, 6 is best**

1= extremely disruptive

1= extremely poor

2= obviously disruptive

2= poor

3= slightly disruptive      **OR**

3= not quite adequate

4= present but not disruptive

4= adequate

5= barely present

5= good

6= not present

6= excellent

FIGURE 4. DIVER-TO-DIVER; NITROX, AVERAGE OF RESPONSES TO QUESTIONNAIRE

An acceptable degree of intelligibility was indicated in open- and closed-circuit modes at both depths. For the questions directly related to speech intelligibility; 2,3 and 4, the average scores were all 4.5 (adequate-to-good) or better for open-circuit mode and 5.0 (good) or better for closed-circuit mode. This small difference again points to the ability of the divers to adapt to the breathing noise experienced in open-circuit mode. There was no significant difference in intelligibility performance between the two test depths.

For questions 1 and 5 that address background noise and comparative distortion there was a significant difference in average scores between open- and closed-circuit modes with closed circuit scores showing more than a 40% improvement. This is attributable solely to the lack of breathing noise in closed circuit mode.

#### Questionnaire Comments

Diver's written responses to questions are found in Appendix A. In general, the responses were favorable and support the assessment of acceptable topside-to-diver intelligibility as indicated by the other evaluation methods.

Despite a number of comments about the breathing noise encountered in open-circuit mode all divers were able to achieve acceptable MRT scores by synchronizing their breathing with the talking diver. This practice is not uncommon as confirmed by one diver who commented; "Necessary to hold breath to communicate but that is not uncommon".

A comment was made from one diver during the open-circuit portion of the 100' nitrox dive; "(Background noise) not because of comms., it was overbottom (pressure) of regulator". This is in reference to the noise created by a free flowing FFM regulator during ascent. This noise was recorded on DAT and can be heard to increase as the divers approached the surface (PVA depressurized). All communications is effectively obscured at ~20 fsw when the free flowing started. With the divers being under only 1 to 3 feet of water (or less) throughout the dive bubbles breaking on the surface may have been a factor in the amount of noise generated. It is apparent that regulator free flow or other sources of background noise should be minimized to maintain intelligibility.

#### Digital Audio Tape Recordings

DAT recordings document a high degree of intelligibility from diver-to-diver. It is apparent that the divers were able to understand each other very well the first time in most cases. In open-circuit mode, if one diver was talking when the other was inhaling, the information sometimes needed to be repeated. Divers quickly learned to synchronize speaking and breathing to maximize intelligibility.

## **Diver-to-topside**

While no objective testing was done during the tests, acceptable diver-to-topside intelligibility can be implied because of the acceptable results obtained for diver-to-diver intelligibility. This is because the audio signal path for diver-to-diver communication passes through the topside communication amplifier where it is monitored/recorded by topside. The intelligibility of this signal is at least as good as that of the signal reaching the headset of the listening diver because there is one less path of potential degradation that the audio signal has to travel through (i.e. topside-to-diver). Also, the headset used by the topside tender has better fidelity than the diver headset and the topside tender can adjust volumes and external noise to improve intelligibility as required. Subjective results support this conclusion

### Modified Rhyme Test Scores

No diver-to-topside MRTs were conducted during the dives. However, the DAT recordings of diver-to-diver MRTs could be used to conduct post dive tests as desired.

### Questionnaire Ratings

Diver-to-topside speech intelligibility was subjectively measured using topside responses to five questions that required a numeric rating from a six-point scale with 6 being the best. An average of these ratings was calculated (figure 5) for each question.

An acceptable degree of intelligibility was indicated in open- and closed-circuit modes. As long as the divers synchronized breathing with talking in open-circuit mode, breathing noise was not a problem. For the questions directly related to speech intelligibility; 2,3 and 4, the average ratings were all 5.0 (good) or better at both depths. The score of 2.0 for question 1 in open-circuit mode at both depths was solely attributable to interpreting breathing noise as background noise.

### Questionnaire Comments

Diver's written responses to questions are found in Appendix A. Comments were made that breathing noise was only disruptive if one diver was inhaling while the other diver was talking. Divers worked to minimize this noise when communicating with topside.

### Digital Audio Tape Recordings

DAT recordings document a high degree of intelligibility from diver-to-topside diver. It is apparent that, in nearly all cases, topside was able to understand the diver very well the first time. In open-circuit mode, if one diver was talking when the other was

| Question | 100 fsw | 100 fsw | 150 fsw | 150 fsw |
|----------|---------|---------|---------|---------|
|          | O - C   | C - C   | O - C   | C - C   |
| 1        | 2.0     | 5.0     | 2.0     | 5.0     |
| 2        | 5.0     | 5.0     | 5.0     | 5.0     |
| 3        | 5.0     | 5.0     | 5.0     | 5.0     |
| 4        | 5.0     | 5.0     | 5.0     | 5.0     |
| 5        | 5.0     | 5.0     | 5.0     | 4.0     |

(Sample size = 2 for 100 fsw O-C, 1 for all others)

#### Key to rated questions; 1 - 5:

Question #1: How would you rate the background noise from the diver?

Question #2: How would you rate the overall clarity of speech from the diver?

Question #3: How would you rate your ability to understand single words from the diver?

Question #4: How would you rate your ability to understand conversation from the diver?

Question #5: How would you rate the level of speech distortion from the diver compared to speech you hear on the surface in a normal conversation?

#### Key to answers: 1 is worst, 6 is best

1= extremely disruptive

1= extremely poor

2= obviously disruptive

2= poor

3= slightly disruptive      OR

3= not quite adequate

4= present but not disruptive

4= adequate

5= barely present

5= good

6= not present

6= excellent

**FIGURE 5. DIVER-TO-TOPSIDE; NITROX, AVERAGE OF RESPONSES TO QUESTIONNAIRE**

inhaling, the information sometimes needed to be repeated. Divers quickly learned to synchronize speaking and breathing to maximize intelligibility.

## **HELIOX DIVES**

Speech intelligibility results and analysis is divided into three sections; topside-to-diver, diver-to-topside, and diver-to-diver. Results with and without an HSU are addressed in each section.

### **Topside-to-diver**

#### Modified Rhyme Test Scores

An acceptable degree of intelligibility was indicated (figure 6) with an average score of 81.3% for all heliox dives and only one score below the minimum acceptable 75%.

The low MRT score of 47.2% was recorded at 300 fsw for diver 2 who indicated, as documented by DAT recordings, that inadequate headset volume was a problem and that a very high level of concentration was required to hear topside. Since this diver responded to only 45 of the 50 words on the MRT, it is apparent that he did not hear some words at all. The MRTs at 90-120 fsw were conducted during several decompression stops for the same 300 fsw dive. Diver 2 indicated that inadequate headset volume was also a problem during these MRTs and is reflected by his 75% score. The explanation for inadequate headset volume is the same as described in the topside-to-diver questionnaire comments section under the results and analysis subheading for the nitrox dives.

#### Questionnaire Ratings

Topside-to-diver speech intelligibility was subjectively measured using diver responses to five questions that required a numeric rating from a six-point scale. An average of these ratings was calculated (Figure 7) for each question.

An acceptable degree of intelligibility was indicated with all of the average scores 4.0 (adequate) or higher. For the questions directly related to speech intelligibility; 2,3 and 4, the average scores were 5.0 (good) or higher. The scores for questions 1 and 5 that address background noise and comparative distortion were lower by nearly a point. This is likely due to the noise created when the communication amplifier's HSU is on.

#### Questionnaire Comments

Diver's written responses to questions are found in Appendix B. In general, the responses were favorable and support the assessment of acceptable topside-to-diver intelligibility as indicated by the other evaluation methods. The "slight distortion" and

| Diver            | 300 fsw | 200 fsw | 90-120 fsw |
|------------------|---------|---------|------------|
| 1                | 87.5    | 90.4    | 87.5       |
| 2                | 47.5    | 100.0   | 75.0       |
| Average:         | 67.5    | 95.2    | 81.3       |
| Overall average: |         |         | 81.3       |

**FIGURE 6. TOPSIDE-TO-DIVER; HELIOX MRT TEST RESULTS (%)**

| Question | 300 fsw | 200 fsw | 100 fsw |
|----------|---------|---------|---------|
| 1        | 4.5     | 4.0     | 4.5     |
| 2        | 5.3     | 5.5     | 5.0     |
| 3        | 5.3     | 5.5     | 5.5     |
| 4        | 5.3     | 5.5     | 5.0     |
| 5        | 4.3     | 4.5     | 4.5     |

(Sample size=4 for 300 fsw, 2 for all others)

**Key to rated questions; 1 - 5:**

Question #1: How would you rate the background noise from topside?

Question #2: How would you rate the overall clarity of speech from topside?

Question #3: How would you rate your ability to understand single words from topside?

Question #4: How would you rate your ability to understand conversation from topside?

Question #5 How would you rate the level of speech distortion from topside compared to speech you hear on the surface in a normal conversation?

**Key to answers: 1 is worst, 6 is best**

1= extremely disruptive

1= extremely poor

2= obviously disruptive

2= poor

3= slightly disruptive      **OR**

3= not quite adequate

4= present but not disruptive

4= adequate

5= barely present

5= good

6= not present

6= excellent

**FIGURE 7. TOPSIDE-TO-DIVER; HELIOX AVERAGE OF RESPONSES TO QUESTIONNAIRE**

"low buzzing" comments from diver 1 on the 100 fsw and 200 fsw dives align with the ratings assigned by this diver for noise and distortion for the same dives.

#### Digital Audio Tape Recordings

DAT recordings document an acceptable degree of intelligibility from topside-to-diver. Divers were obviously able to understand topside information the first time it was presented in nearly all cases regardless of depth.

#### **Diver-to-topside**

##### Modified Rhyme Test Scores

No diver-to-topside MRTs were conducted during the dives. DAT recordings of the diver-to-diver MRTs could have been used to conduct post-dive diver-to-topside MRTs. However, due to time constraints this was not done. It was felt that the positive subjective results (see below) were enough to indicate that the diver microphone in conjunction with the communication amplifier could produce intelligible helium speech. Diver-to-topside MRTs were conducted using data from subsequent manned intelligibility tests in the Ocean Simulation Facility (OSF) at NEDU<sup>7</sup>.

##### Questionnaire Ratings

Diver-to-topside speech intelligibility was subjectively measured using topside responses to five or six questions that required a numeric rating from a six-point scale with 6 being the best. An average of these ratings was calculated for each question and for each dive depth. Ratings for dives with the HSU on are shown in (Figure 8) and those with the HSU off are shown in (Figure 9).

With the HSU on, the individual and overall averages for the 200 fsw and 300 fsw dives clustered around 4.0 (adequate) for questions 2, 3 and 4, the most direct indication of intelligibility. The overall average for background noise, question 1, was 4.3 (present but not disruptive) or better and the overall average for comparative speech distortion, questions 5 and 6, clustered around 3.0 (slightly disruptive).

With the HSU off, the average ratings to questions 2,3 and 4 for the 100 fsw dive were 4.5 (adequate to good) or better. Below 100 fsw this average was no better than 3.0 (not quite adequate) and got worse as the depth increased. Average ratings for background noise stayed near 4.5 for all depths and average scores for comparative distortion rated 2.0 or lower for all dives. As indicated on the questionnaires, the poor distortion rating was attributable to the "donald duck" high frequency speech sound caused by the increase in helium partial pressure.

| Question | 300 fsw | 200 fsw | Overall average<br>200 & 300 fsw |
|----------|---------|---------|----------------------------------|
| 1        | 4.7     | 4.3     | 4.5                              |
| 2        | 4.4     | 4.0     | 4.2                              |
| 3        | 3.9     | 3.7     | 3.8                              |
| 4        | 4.2     | 3.7     | 4.0                              |
| 5        | 3.0     | 3.0     | 3.0                              |
| 6        | 2.9     | 2.3     | 2.6                              |

**Key to rated questions: 1 - 6:**

Question #1: How would you rate the background noise from the diver?

Question #2: How would you rate the overall clarity of speech from the diver?

Question #3: How would you rate your ability to understand single words from the diver?

Question #4: How would you rate your ability to understand conversation from the diver?

Question #5: How would you rate the level of speech distortion from the divers with this HSU compared to speech you hear on the surface in a normal conversation?

Question #6: How would you rate the level of speech distortion from the divers with this HSU, compared to speech you hear using air communication systems during a working dive?

**Key to answers: 1 is worst, 6 is best**

1= extremely disruptive

2= obviously disruptive

3= slightly disruptive

4= present but not disruptive

5= barely present

6= not present

**OR**

1= extremely poor

2= poor

3= not quite adequate

4= adequate

5= good

6= excellent

**FIGURE 8. DIVER-TO-TOPSIDE, HELIOX, HSU ON, AVERAGE OF RESPONSES TO QUESTIONNAIRE**

| Question | 300 fsw | 200 fsw | 100 fsw | Overall average<br>100,200,300 fsw |
|----------|---------|---------|---------|------------------------------------|
| 1        | 4.7     | 4.3     | 4.5     | 4.5                                |
| 2        | 1.5     | 3.0     | 5.0     | 3.2                                |
| 3        | 1.4     | 3.0     | 5.0     | 3.1                                |
| 4        | 1.4     | 2.0     | 4.5     | 2.6                                |
| 5        | 1.4     | 1.7     | 2.0     | 1.7                                |

**Key to rated questions; 1 - 5:**

- Question #1: How would you rate the background noise from the diver?

Question #2: How would you rate the overall clarity of speech from the diver?

Question #3: How would you rate your ability to understand single words from the diver?

Question #4: How would you rate your ability to understand conversation from the diver?

Question #5: How would you rate the level of speech distortion from the divers with this HSU compared to speech you hear on the surface in a normal conversation?

**Key to answers: 1 is worst, 6 is best**

- 1= extremely disruptive**
- 2= obviously disruptive**
- 3= slightly disruptive**
- 4= present but not disruptive**
- 5= barely present**
- 6= not present**

**OR**

- 1= extremely poor
- 2= poor
- 3= not quite adequate
- 4= adequate
- 5= good
- 6= excellent

**FIGURE 9. DIVER-TO-TOPSIDE, HELIOX, HSU OFF, AVERAGE OF RESPONSES TO QUESTIONNAIRE**

### Questionnaire Comments

Diver's written responses to questions are found in Appendix B. Topside indicated that speech was not intelligible at 200 fsw or 300 fsw without using the HSU.

### Digital Audio Tape Recordings

DAT recordings of diver-to-diver MRTs and general round-robin conversation were used to subjectively evaluate diver-to-topside intelligibility. Evaluation was done by two methods. The first was to listen to the DAT recordings of the MRTs that were conducted with the HSU on (unscrambled speech). For this evaluation it should be noted that limited bottom time and limited operator experience resulted in less than optimal HSU adjustment during these tests. The second method was to use DAT recordings of scrambled helium speech obtained during MRTs that were conducted with the HSU off. The scrambled speech recordings were fed into the microphone input of the communication amplifier and the HSU controls were adjusted to obtain the best intelligibility. Being able to repeatedly simulate the dives by using the recordings was valuable for gaining HSU adjustment experience and evaluating the best possible performance of diver-to-topside communication.

DAT recordings of unscrambled helium speech document an acceptable degree of intelligibility from diver-to-topside. It is apparent that, in nearly all cases, topside was able to understand the diver very well the first time.

Evaluation of the scrambled helium speech DAT recording played into the communication amplifier yielded acceptable intelligibility results also. When using this method, there is an increase in communication amplifier noise since the speech is processed twice by the amplifier; once to obtain the original scrambled helium speech recording and then again, post-dive, when the recording is played back into the amplifier and the HSU is adjusted for the intelligibility evaluation. Even with the extra noise, better intelligibility than the unscrambled DAT recordings was generally obtained using this method because the HSU controls could be optimally adjusted.

### Helium Speech Unscrambler Requirement

One of our goals was to determine at what depth it becomes necessary to use an HSU to obtain acceptable speech intelligibility with divers breathing a MK-16 heliox mix. Subjective results from DAT tapes and from comments by topside personnel, who listened while the divers were reading during their ascent and descent, indicate that scrambled helium speech can be understood by relatively inexperienced topside personnel without use of an HSU to a depth of approximately 100 fsw. Intelligibility rapidly drops off below this depth. This is supported by results from the diver-to-topside questionnaire where ratings on questions 2, 3 and 4 ranged from 4.5 to 5.0 (adequate

to good) for the 100 fsw dive and 1.4 to 3.0 (extremely poor to not quite adequate) for the 300 and 200 fsw dives. The depth below which the speech becomes unintelligible varies as a function of hearing ability of the individual and the amount of experience that individual has had listening to scrambled helium speech. Anecdotally, as the experience level of the individual increases, the depth to which scrambled helium speech can be understood appears to increase.

### Diver-to-diver

#### Modified Rhyme Test Scores

As can be seen in Figure 10, diver-to-diver MRT scores were generally very poor both with and without use of the HSU. There were only four instances where the minimum acceptable 60% score was achieved, once with the HSU and three times without. However, all but one were achieved at the shallowest test depths where HSU adjustment is not as critical and, in fact, the necessity of an HSU is debatable. The scores for divers 1 and 2 from the first 300 fsw dive were typically much lower than those for divers 3 and 4 on the second 300 fsw dive. This was likely due to the following: divers 1 and 2 reading their word lists to each other much too fast in an effort to minimize decompression time, lack of topside experience in adjusting the HSU for the first 300 fsw dive, and inadequate headset volume for diver 2.

In all but one case diver-to-diver MRT scores were better without the HSU than with the HSU. At first glance this is counter intuitive but a probable explanation is; 1. the divers became used to heliox speech with their dive partner prior to the MRT, 2. the divers had limited or no previous experience with HSU speech prior to the MRT, 3. the short bottom time of the dive resulted in rushed HSU adjustments by inexperienced topside personnel with regard only for diver-to-topside intelligibility and not diver-to-diver intelligibility, 4. HSU adjustments were sometimes made during the MRTs in the interests of improving diver-to-topside intelligibility which has a higher program priority than diver-to-diver intelligibility.

#### Questionnaire Ratings

Diver-to-diver speech intelligibility was subjectively measured using topside responses to six questions that required a numeric rating from a six-point scale with 6 being the best. An average of these ratings was calculated for each question and for each dive depth. Ratings for dives with the HSU on are shown in (Figure 11) and those with the HSU off are shown in (Figure 12). No questionnaire responses were obtained for the 100 fsw with the HSU on.

There were poor results at all depths regardless of HSU status. Average ratings ranged from 2.0 (poor) to 3.5 (less than adequate) for questions 2, 3 and 4, the most direct indication of intelligibility. The average ratings for background noise, question 1, was 4.0 (present but not disruptive) or better and the overall average for comparative

| Diver    | 90-120 fsw<br>HSU on | 90-120 fsw<br>HSU off | 200 fsw<br>HSU on | 200 fsw<br>HSU off | 300 fsw<br>HSU on | 300 fsw<br>HSU off |
|----------|----------------------|-----------------------|-------------------|--------------------|-------------------|--------------------|
| 1        | 35.0                 | <b>67.5</b>           | 22.5              | 45.0               | 2.7               | 40.5               |
| 2        | 31.1                 | 37.5                  | 49.3              | <b>60.0</b>        | n/a               | 20.0               |
| 3        | 48.9                 | <b>70.0</b>           | n/a               | n/a                | 34.9              | 35.0               |
| 4        | <b>60.0</b>          | 57.5                  | n/a               | n/a                | 32.5              | 45.0               |
| Average: | 43.8                 | 58.1                  | 35.9              | 52.5               | 23.4              | 35.1               |

FIGURE 10. DIVER-TO-DIVER; HELIOX MRT TEST RESULTS (%)

| Question | 300 fsw | 200 fsw | 100 fsw |
|----------|---------|---------|---------|
| 1        | 4.5     | 3.5     | n/a     |
| 2        | 2.3     | 3.0     | n/a     |
| 3        | 2.3     | 3.0     | n/a     |
| 4        | 2.5     | 2.5     | n/a     |
| 5        | 1.5     | 3.5     | n/a     |
| 6        | 1.8     | 3.0     | n/a     |

(Sample size=4 for 300 fsw, 2 for all others)

**Key to rated questions; 1 - 6:**

Question #1: How would you rate the background noise from the other diver?

Question #2: How would you rate the overall clarity of speech from the other diver?

Question #3: How would you rate your ability to understand single words from the other diver?

Question #4: How would you rate your ability to understand conversation from the other diver?

Question #5: How would you rate the level of speech distortion from the other diver compared to speech you hear on the surface in a normal conversation?

Question #6: How would you rate the level of speech distortion from the other diver compared to speech you hear using air communication systems during a working dive?

1= extremely disruptive

2= obviously disruptive

3= slightly disruptive

4= present but not disruptive

5= barely present

6= not present

1= extremely poor

2= poor

3= not quite adequate

4= adequate

5= good

6= excellent

OR

**FIGURE 11. DIVER-TO-DIVER; HELIOX, HSU ON, AVERAGE OF RESPONSES TO QUESTIONNAIRE**

| Question | 300 fsw | 200 fsw | 100 fsw |
|----------|---------|---------|---------|
| 1        | 5.0     | 4.0     | 4.5     |
| 2        | 2.5     | 3.0     | 2.0     |
| 3        | 2.3     | 2.5     | 3.5     |
| 4        | 2.3     | 3.0     | 3.0     |
| 5        | 2.0     | 2.0     | 2.5     |
| 6        | 2.3     | 3.0     | 2.5     |

(Sample size=4 for 300 fsw, 2 for all others)

#### Key to rated questions; 1 - 6:

Question #1: How would you rate the background noise from the other diver?

Question #2: How would you rate the overall clarity of speech from the other diver?

Question #3: How would you rate your ability to understand single words from the other diver?

Question #4: How would you rate your ability to understand conversation from the other diver?

Question #5: How would you rate the level of speech distortion from the other diver compared to speech you hear on the surface in a normal conversation?

Question #6: How would you rate the level of speech distortion from the other diver compared to speech you hear using air communication systems during a working dive?

1= extremely disruptive

1= extremely poor

2= obviously disruptive

2= poor

3= slightly disruptive

OR

3= not quite adequate

4= present but not disruptive

4= adequate

5= barely present

5= good

6= not present

6= excellent

**FIGURE 12. DIVER-TO-DIVER; HELIOX, HSU OFF, AVERAGE OF RESPONSES TO QUESTIONNAIRE**

speech distortion, questions 5 and 6, clustered just around below 2.0 (obviously disruptive). There was no significant difference in average ratings with the HSU on versus with the HSU off.

#### Questionnaire Comments

Written diver comments to the questionnaire are provided in Appendix B. These comments support the assessment of generally poor diver-to-diver intelligibility as indicated by the MRT scores and the questionnaire ratings.

#### Digital Audio Tape Recordings

Although the DAT recordings generally document poor diver-to-diver communication, they also document a number of instances where it is obvious that intelligible diver-to-diver conversations is taking place.

#### Alternate Communication Amplifier

An alternate communication amplifier was informally tested very briefly during some of the decompression stops. However, because of the informal nature of these test and because no MRTs were conducted it's performance is not reported here. Testing of alternate communication amplifiers will be the subject of a follow on study.

## CONCLUSIONS

For a nitrox breathing medium, the objective and subjective results indicate that the EBS-II communication system components, as tested, can produce acceptable round-robin intelligibility to 150 fsw. No significant difference in intelligibility was observed between 100 fsw and 150 fsw.

For a heliox breathing medium, acceptable diver-to-topside and topside-to-diver intelligibility was obtained using these same components. Poor diver-to-diver intelligibility was presumably a result of limited bottom time, inadequate HSU adjustment, and lack of diver experience with unscrambled (HSU on) and scrambled (HSU off) helium speech. This could be expected to improve with experience.

Now an alternate communication amplifier can be integrated into the system in place of the Hydrocom so it's performance can be evaluated. This amplifier should be able to produce acceptable intelligibility results using the same components under the same or similar test conditions.

Subjective results (questionnaires, DAT recordings, etc.) indicate that scrambled helium speech from divers can be understood by topside personnel, who are relatively inexperienced with helium speech, down to a depth of approximately 100 fsw.

## **RECOMMENDATIONS**

The communication components of the EBS-II system, as tested, are recommended for use by EOD to support round robin communication for nitrox diving as well as topside-to-diver and diver-to-topside communication for heliox diving.

It is further recommended that NEDU proceed with testing the intelligibility performance of an alternate communication amplifier by substituting it in place of the Hydrocom amplifier and conducting similar system level testing using the same EBS-II communication system components.

## REFERENCES

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2. MIL-STD-1472D Notice 3, *Human Engineering Design Criteria For Military Systems, Equipment, and Facilities*, Department of Defense, Washington, DC, 10 February 1994, p. 65.
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6. Mendel, L.L., Hamill, B.W., Crepeau, L.J., Fallon, E., "Speech Intelligibility Assessment in a Helium Environment," *Journal of the Acoustical Society of America*, Vol. 97, No. 1, January 1995, pp. 628-636.
7. M.J. Fennewald and W.D. Olstad, *Intelligibility Assessment of EBS-II Diver Communications Using an Amron Communication Amplifier with Nitrox and Heliox Breathing Mediums*, NEDU TR 3-97, Navy Experimental Diving Unit, June 1997.

## APPENDIX A

### Figure A1 MRT Reading List

#### MRT LIST R1-E

|          |          |         |
|----------|----------|---------|
| 1 badge  | 18 has   | 35 veal |
| 2 lob    | 19 wean  | 36 tame |
| 3 wick   | 20 sap   | 37 then |
| 4 dove   | 21 sheaf | 38 fin  |
| 5 cud    | 22 sick  | 39 gin  |
| 6 dill   | 23 sung  | 40 zee  |
| 7 dug    | 24 tap   | 41 tent |
| 8 fib    | 25 teeth | 42 lip  |
| 9 lead   | 26 fed   | 43 shop |
| 10 tog   | 27 gold  | 44 roar |
| 11 lath  | 28 pig   | 45 high |
| 12 mass  | 29 sick  | 46 ship |
| 13 bays  | 30 thin  | 47 west |
| 14 pat   | 31 park  | 48 dust |
| 15 peat  | 32 male  | 49 rat  |
| 16 pitch | 33 keel  | 50 nay  |
| 17 pus   | 34 bill  |         |

Figure A2  
MRT Response Sheet

NAME: \_\_\_\_\_

RIG OR LOCATION: \_\_\_\_\_ DATE \_\_\_\_\_

RESPONSE SHEET 2-R1

|    | A       | B      | C     | D      | E      |    | A    | B     | C    | D     | E   |
|----|---------|--------|-------|--------|--------|----|------|-------|------|-------|-----|
| 1  | bat     | batch  | badge | bass   | bash   | 26 | wed  | red   | led  | fed   | she |
| 2  | lob     | log    | lodge | laws   | long   | 27 | sold | cold  | hold | gold  | tol |
| 3  | wit     | wig    | wick  | with   | witch  | 28 | big  | wig   | dig  | rig   | pig |
| 4  | duff    | doth   | dove  | dumb   | dub    | 29 | kick | chick | pick | thick | sic |
| 5  | cup     | cuff   | cub   | cud    | cut    | 30 | thin | tin   | kin  | fin   | shi |
| 6  | dig     | dill   | din   | dim    | did    | 31 | bark | mark  | park | lark  | dar |
| 7  | dung    | dun    | dud   | dug    | dub    | 32 | tale | pale  | bale | gale  | mal |
| 8  | fin     | fill   | fig   | fib    | fizz   | 33 | keel | peel  | eel  | heel  | fee |
| 9  | leash   | leave  | lead  | liege  | leach  | 34 | hill | till  | kill | will  | bil |
| 10 | tog     | toss   | taj   | talks  | tong   | 35 | reel | veal  | feel | zeal  | sea |
| 11 | lash    | lath   | lass  | laugh  | lack   | 36 | game | shame | came | tame  | sam |
| 12 | mat     | mass   | man   | mad    | math   | 37 | den  | pen   | hen  | ten   | the |
| 13 | bayed   | base   | bathe | bays   | beige  | 38 | win  | fin   | sin  | pin   | tin |
| 14 | pad     | pass   | pat   | pack   | path   | 39 | shin | chin  | thin | tin   | gin |
| 15 | peat    | peak   | peal  | peas   | peace  | 40 | knee | dee   | thee | zee   | lee |
| 16 | pick    | pit    | pip   | pitch  | pig    | 41 | went | tent  | bent | rent  | den |
| 17 | pup     | pus    | pub   | puck   | puff   | 42 | rip  | dip   | tip  | hip   | lip |
| 18 | has     | have   | half  | hash   | hath   | 43 | cop  | hop   | top  | shop  | pop |
| 19 | weed    | wean   | we're | weave  | weal   | 44 | yore | gore  | wore | lore  | roa |
| 20 | sack    | sap    | sat   | sad    | sag    | 45 | fie  | vie   | high | thy   | thi |
| 21 | sheathe | sheave | sheaf | sheath | sheen  | 46 | ship | lip   | gyp  | zip   | nip |
| 22 | sin     | sit    | sing  | sick   | sip    | 47 | best | west  | vest | nest  | res |
| 23 | sun     | sung   | sud   | sum    | sub    | 48 | dust | just  | gust | bust  | rus |
| 24 | tan     | tab    | tap   | tang   | tam    | 49 | rat  | mat   | vat  | that  | fat |
| 25 | tear    | teeth  | tease | teel   | teethe | 50 | may  | they  | gay  | way   | nay |

## **APPENDIX B**

### **WRITTEN COMMENTS FROM QUESTIONNAIRES, 100 fsw NITROX**

The comments from the questionnaires used for the 100 fsw and 150 fsw nitrox dives are presented here. In some cases comments were identical between respondents. These are only listed once. Comments enclosed in "{}" are those of the author added for clarity.

#### **100 fsw**

##### **Diver-to-topside open-circuit**

HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?

- Adequately reproduces it

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- None
- Breathing noise

##### **Diver-to-topside closed-circuit**

HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?

- Adequately reproduces it

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- None

##### **Diver-to-diver open-circuit**

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No

#### **ADDITIONAL COMMENTS**

- Necessary to hold breath to communicate but that is not uncommon
- {Background noise} not because of comms., it was overbottom {pressure} of regulator. {causing free flow of regulator}

#### **Diver-to-diver closed-circuit**

No comments provided.

#### **Topside-to-diver open/closed-circuit**

#### **WHICH SPEECH SOUNDS CAME THROUGH THE BEST?**

- I could understand all pretty good

#### **WHICH SPEECH SOUNDS CAME THROUGH THE WORST?**

- None

#### **DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?**

- No

#### **150 fsw**

#### **Diver-to-topside open-circuit**

#### **ADDITIONAL COMMENTS**

- Generally comms. very clear. Any inhalation noise made it nearly impossible for anybody to hear anyone else that might have been talking at that time. Must synchronizing breathing.

#### **Diver-to-topside closed-circuit**

#### **HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?**

- Faithful reproduction, maybe exaggerated treble or less base

#### **WHICH SPEECH SOUNDS CAME THROUGH THE BEST?**

- All

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- All

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No

**Diver-to-diver open-circuit**

HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?

- Little distortion
- Amplifies everything including his breathing

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- All pretty good

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- Don't know

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- Breathing noise
- Sometimes it would sound like it's echoing.

**ADDITIONAL COMMENTS**

- Same as 100 fsw dive. Breath hold to hear.

**Diver-to-diver closed-circuit**

HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?

- Little or no distortion
- Sounds good

**WHICH SPEECH SOUNDS CAME THROUGH THE BEST?**

- All pretty good

**WHICH SPEECH SOUNDS CAME THROUGH THE WORST?**

- Didn't hear any

**DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?**

- No

**Topside-to-diver open/closed-circuit**

**DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?**

- No

**ADDITIONAL COMMENTS**

- Couldn't turn up ears enough to hear over any other breathing noise. Couldn't understand unless I concentrated real hard.

## APPENDIX C

### WRITTEN COMMENTS FROM QUESTIONNAIRES, HELIOX DIVES

The comments from the questionnaires used for the 100, 200 and 300 fsw heliox dives are presented here. In some cases comments were identical between respondents. These are only listed once. Comments enclosed in "{}" are those of the author added for clarity. Questions to which there were no responses are left out.

#### 100 fsw

##### Diver-to-topside without HSU

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- None

##### Topside-to-diver

HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD FROM TOPSIDE?

- Slight distortion
- Very clear, I noticed no distortion

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- Normal speech sounds
- All

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- None

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No

##### ADDITIONAL COMMENTS

- Sounds great!

**Diver-to-diver without HSU**

HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?

- Muffled, sounds like talking from under a pillow.

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- Short words
- All the same

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- All the same
- Long words

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No

ADDITIONAL COMMENTS

- Clear up the mic.

**200 fsw**

**Diver-to-topside without HSU**

HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?

- I could understand speech to about 150 fsw.
- @ >= 100 - 140 fsw could not understand without HSU
- Nothing

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- Words with "D", "T", "P"

**WHICH SPEECH SOUNDS CAME THROUGH THE WORST?**

- Words with "S", "M"

**DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?**

- None

**Diver-to-topside with HSU**

**HOW WOULD YOU DESCRIBE WHAT THIS HSU DOES TO THE SPEECH YOU HEARD?**

- Deepens and slows it
- Makes a big difference/more natural

**DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?**

- None

**Topside-to-diver**

**HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?**

- Slightly distorted
- Very clear, no problem understanding topside

**WHICH SPEECH SOUNDS CAME THROUGH THE BEST?**

- Short word/sentences
- All

**DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?**

- Low buzzing
- An almost non-existent high pitch hiss...

**ADDITIONAL COMMENTS**

- {comms. were} great.

### **Diver-to-diver without HSU**

HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?

- Muffled sound
- Picking out individual words was difficult, but I could understand conversation.

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- Short words.

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- Long sentences

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No

### ADDITIONAL COMMENTS

- Cut out the base, bring up the treble.

### **Diver-to-diver with HSU**

HOW WOULD YOU DESCRIBE WHAT THIS HSU DOES TO THE SPEECH YOU HEARD?

- Speech became tinny
- Makes it extremely difficult to understand

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- None

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- All

**DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?**

- No, background high pitch hiss, no discomfort.
- No

**ADDITIONAL COMMENTS**

- Too much base.

**300 fsw**

**Diver-to-topside without HSU**

**HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?**

- HEO2 speech became hard to understand after about 150 fsw.
- Nothing
- Extremely poor {intelligibility} below 130 fsw.
- Good {intelligibility} at stops < 100 fsw.

**WHICH SPEECH SOUNDS CAME THROUGH THE BEST?**

- Red diver seemed easier to understand.
- Words with "sh" sounds

**DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?**

- No

**Diver-to-topside with HSU**

**HOW WOULD YOU DESCRIBE WHAT THIS HSU DOES TO THE SPEECH YOU HEARD?**

- It slowed down the rate making it easier to understand.
- Eliminates "donald duck" effect
- Improves {speech} so it is understandable when it would not be without it.
- Eliminates "donald duck" effect but speech was still muffled

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- Red diver sounds better.
- All

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- None

#### **Topside-to-diver**

HOW WOULD YOU DESCRIBE WHAT THIS COMM. SYSTEM DOES TO THE SPEECH YOU HEARD?

- Speech is clear from topside
- Same as before, topside very clear

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- Short word/sentences
- All

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No

#### **ADDITIONAL COMMENTS**

- Wear the headset outside of the {MK-24 FFM} spider straps so your ears don't hurt from contact with earphones.

#### **Diver-to-diver without HSU**

HOW WOULD YOU DESCRIBE WHAT THIS HSU DOES TO THE SPEECH YOU HEARD?

- Muffled
- Easier to understand speech rather than single words.
- Voice distortion due to HE and depth prominent
- Muffles words

### **WHICH SPEECH SOUNDS CAME THROUGH THE BEST?**

- Single words
- All conversation
- None

### **WHICH SPEECH SOUNDS CAME THROUGH THE WORST?**

- Long sentences
- Single words
- "R", "S", "M", all others

### **DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?**

- No

### **ADDITIONAL COMMENTS**

- It seemed easier to understand conversation with other diver without HSU.

### **Diver-to-diver with HSU**

### **HOW WOULD YOU DESCRIBE WHAT THIS HSU DOES TO THE SPEECH YOU HEARD?**

- Distorts your words
- Delay time between start of speech, sounds like you are grumbling.
- Not much difference
- Muffles words

### **WHICH SPEECH SOUNDS CAME THROUGH THE BEST?**

- Single words
- Conversation
- None

### **WHICH SPEECH SOUNDS CAME THROUGH THE WORST?**

- Long sentences
- Single words
- "R", "S", "M", all others

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No

ADDITIONAL COMMENTS

- {None}

## **APPENDIX D**

### **DETAILED DESCRIPTION OF DIVER HEADSET AND MICROPHONES**

#### **Diver Headset**

The diver headset used for the EBS-II diver communication system is the same as that designed for use with the AN/PQS-2A sonar. It is waterproof to 500 psi, features left and right ear pieces fabricated using piezo-ceramic crystal speaker elements and meets the magnetic signature requirements for contact items as per MIL-M-1949C Amendment 1. The headset is designed to have a capacitance between .135 microfarads and .215 microfarads at a frequency of 1 KHz. This presents a nominal load impedance of approximately 1K Ohm to the communication amplifier at this frequency. It is also designed to be driven by the sonar with an AC sine wave between 7 volts and 14 volts peak-to-peak. The headset cable has an underwater mateable, 2 contact, male connector on the end. The ear pieces are typically put in a skull cap and the skull cap is placed over the diver's head. The part number is 1100-5002-1. It is listed in the national stock system under NSN #5965-01-278-2082 and is manufactured by either Datasonics Inc., FSCM No. 4U270, or SeaBeam Instruments Inc., FSCM No. 02131.

#### **Diver Microphone**

This is a preamplified, piezoelectric compression type microphone detailed in CSS drawing #6696997. It is currently issued with the MK-24 FFM. It screws into the side of the open/closed-circuit switchover block on the MK-24 FFM so that the front face is oriented perpendicular to the sound source in the oral/nasal cavity of the mask and flush with the interior surface. The preamplifier for this microphone is bipolar and is based on a discrete transistor design. It requires a minimum of 6.5 volts DC and 2.3 milliamperes from the communication amplifier's powered microphone bias circuit to operate properly. The preamplifier frequency response curve peaks at approximately 4kHz and is -3dB at 1.3 kHz and 10.1 kHz with a slope of +/-20 dB/decade at these points. The microphone cable has an underwater mateable, 2 contact, female male connector on the end.